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Ocular prevalence versus ocular dominance

Guntram Kommerell *, Christina Schmitt, Miriam Kromeier, Michael Bach

Abteilung Neuroophthalmologie und Schielbehandlung, Universitäts-Augenklinik, Killianstrassae 5, Freiburg 79106, Germany

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Abstract

Ocular dominance manifests itself in tests that contain stereo-objects with a disparity beyond Panum's area, e.g. in pointing a finger. These tests force subjects to decide in favour of one or the other eye. In contrast, *ocular prevalence* is determined using stereo-targets imaged within Panum's areas. These tests allow a graded quantification of the balance between the eyes. Here we present the computer-based Freiburg Ocular Prevalence Test in which stereo-disparate targets have to be aligned, and compare it with the Haase Stereo-balance Test that requires an estimation of the horizontal distance between stationary stereo-disparate objects. In addition, we compare ocular prevalence with ocular dominance. *Methods*: (1) We measured the influence of a neutral-grey filter in front of one eye to assess the suitability of the Freiburg and the Haase Tests in revealing graded amounts of ocular prevalence. (2) About 20 subjects with equal vision of their two eyes underwent the Freiburg and the Haase Tests for ocular prevalence, and Parson's Monoptoscope Test for ocular dominance. *Results*: (1) In both the Freiburg and the Haase Tests, the neutral-grey filter shifted ocular prevalence by about 50%. (2) An ocular prevalence of more than 10% occurred in 13 of the 20 subjects using the Freiburg, and in 14 using the Haase Test. On average, the ocular prevalence was $24.1 \pm 3.8\%$ in the Freiburg and $32.0 \pm 8.2\%$ in the Haase Test. The dominant eye coincided with the prevalent eye in 15 of the 20 subjects. *Discussion*: The effect of the neutral-grey filter indicated that both the Freiburg and the Haase Tests can be used to measure fractions of ocular prevalence, although the Freiburg Test carries a higher reproducibility. Spontaneous ocular prevalence occurs frequently in persons with equal vision of their two eyes. This suggests that ocular prevalence does not represent a condition that requires treatment. Rather, partial suppression of one eye, the correlate of ocular prevalence, may play a physiological role in that it helps to disregard double images at stereo-disparities close to the limits of Panum's area.

Keywords: Ocular prevalence; Eye dominance; Stereopsis; Fixation disparity

1. Introduction

Rosenbach (1903) discovered that most people have a dominant eye, even though each of their two eyes in isolation may provide equal vision. He applied a simple sighting test: with both eyes open, subjects are requested to aim with one of their index fingers at a distant target. As the finger is imaged outside Panum's area, it appears doubled. Most people prefer the image of one eye to that of the other. The dominant eye can be identified by alternate occlusion: when viewing with the dominant eye the index finger is aligned with the target, whereas when viewing with the other eye the index finger appears offset to one side.

The eye that dominates in Rosenbach's sighting test is not always the eye with the better visual acuity nor the "winning" eye in tasks for binocular rivalry of form or colour (Walls, 1951). Furthermore, the eye preferred for sighting does not indicate handedness (Miles, 1930; Sachsenweger, 1958). This is not surprising since each eye projects to both cerebral hemispheres, whereas each hand is represented mainly in the opposite hemisphere.

Hillemanns (1927) confirmed Rosenbach's finding. In his study of 400 non-strabismic subjects, about 40% showed a dominance of the right and about 20% of the left eye. About 40% felt uncertain which of the index finger's double images they should align with the target, and when forced to choose they varied on repeated testing. Similar results were obtained with several other sighting tests (Coren & Kaplan, 1973; Crider, 1944; Porac & Coren, 1976).

Tests for ocular dominance, such as pointing a finger or aiming a gun force the subject to choose one eye for

* Corresponding author. Tel.: +49-76-66-2791; fax: +49-761-270-4114.

E-mail address: kommerell@aug.ukl.uni-freiburg.de (G. Kommerell).

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alignment. An alternation between the right and left eye can only be expected in subjects who value the images of the two eyes about the same. Even a slight preponderance can shift the responses to 100% in favour of one eye.

A graded quantification of the balance between the eyes is, however, possible with tests for ocular prevalence. Characteristic for these tests is a limitation of stereo-disparity to Panum's area, so that the subject is not forced to choose between double images. Following this approach, Sachsenweger (1958) presented two targets at a stereo-disparity of 7′ in the midline between the two eyes. Most of his 102 stereo-competent subjects saw a horizontal displacement of the two targets against each other. By adjusting the position of the two targets until the subject perceived them aligned, Sachsenweger quantified the prevalence of one eye over the other.

Opinions differ as to whether the prevalence of one eye serves a purpose or indicates a pathological condition. Lang (1994) proposed that prevalence of one eye is due to a partial suppression of the other eye that renders double images at the border of Panum's areas inconspicuous. Haase (1995), on the other hand, suggested that prevalence of one eye indicates a small deviation of the other eye from the fixation point, the so-called fixation disparity, which can be, and should be eliminated by phoria-correcting prisms in patients who suffer from eye strain.

To solve this issue, it should be helpful to know how ocular prevalence is distributed in non-squinting people. We examined this question, applying two different strategies. In the first, we asked subjects to align two stereo-disparate targets, using the newly developed "Freiburg Ocular Prevalence Test", an electronic version of Sachsenweger's (1958) mechanical apparatus. In the second strategy, subjects had to estimate any perceived offset between two stereo-disparate targets that were presented in fixed positions along the midline. For the second strategy, we used the Haase Stereo-balance Test. Following an idea of Sachsenweger (1958), we put both strategies to the test by examining how much a grey filter in front of one eye shifts the prevalence towards the other eye.

We further compared ocular prevalence with ocular dominance, as determined by Parson's Monoptoscope Test (Duke-Elder, 1968; Miles, 1930). In this test, a funnel shields double images off and, thus, forces subjects to favour one of their eyes.

2. Methods

2.1. The Freiburg Ocular Prevalence Test

The stimulus was presented at a distance of 4.5 m on a visual display unit (GD403, Richardson Electronics), 36 cm wide and 27 cm high, with a resolution of 800×600 pixels and a frame rate of 120 Hz. The monitor was driven from the mainboard graphics card of a standard computer (Macintosh G4). The software for generating the stimulus was written in C++.

A pair of liquid crystal shutter goggles (ELSA 3D REVELATOR infrared-version) achieved a nearly complete separation between the right and left eye. The voltage applied to the liquid crystals controlled their transparency. The shutter goggles were synchronised to the monitor frequency so that every second image was presented to the right and left eye, respectively. Each eye received its image at a frequency of 60 Hz, just above flicker fusion frequency.

The stimulus consisted of two equilateral triangles with a side length of 23′, one above the other (Fig. 1). The vertical gap between them was 3.5′. A frame with a height of 69′, a horizontal extension of 92′ and a thickness of 1.4′ surrounded the triangles. The frame was divided in the middle by a horizontal bar of 1.4′ thickness. A pattern with random black and white squares with an edge length of 3′ surrounded the frame. The luminance of the triangles, the frame and the surrounding random squares, measured through the liquid crystal shutter goggles, was approximately 1.8 cd/m^2 and that of the background approximately 40 cd/m^2. We presented the triangles with a disparity of 4.5′, the maximum tolerated without double vision by 10 subjects in a preliminary study. The upper triangle appeared with a stereo-disparity of 2.25′ behind the frame, and the lower triangle with a stereo-disparity of 2.25′ in front of the frame.

At the start of each trial, the tips of the triangles were not vertically aligned: either the upper triangle was offset by 2.25′ to the left and the lower by 2.25′ to the right from the middle of the frame, or vice versa. The task of the subject was to vertically align the triangles by pressing the appropriate one of two buttons. Each displacement of the upper triangle to one side was associated with a similar displacement of the lower triangle to the other side. A short touch of one of the buttons shifted the triangles by 0.35′; a longer touch shifted them continuously. The time to align the tips of the triangles

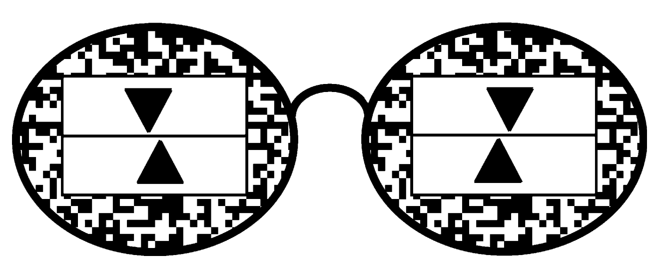

Fig. 1. The Freiburg Ocular Prevalence Test. The upper triangle appears behind, the lower triangle in front of the reference plane (frame and random squares).

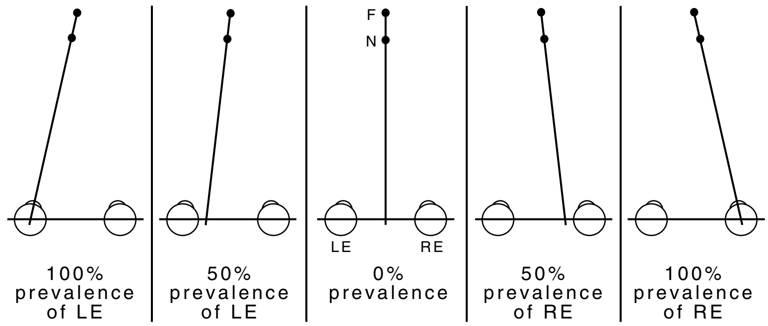

Fig. 2. Measuring ocular prevalence. The subject has to align a far (F) and a near (N) target in the horizontal eye-level plane. The line running through the two targets intersects the interocular axis at some point between the eyes. The intersection can be imagined as the fictive vantage point from which the two targets appear in the same direction. If both eyes contribute equally to the directional perception, the vantage point falls halfway between the eyes. Any prevalence of one eye shifts the vantage point away from the midposition. Five possibilities are depicted, ranging from 100% prevalence of the left eye to 100% prevalence of the right eye.

was limited to 10 s. While the subjects made the alignments, they were free to fixate any part of the stimulus.

An objective alignment of the two triangles was taken as "zero prevalence". If the subject set the upper, posterior triangle by 2.25′ to the left and the lower, anterior triangle by 2.25′ to the right, a 100% prevalence of the right eye was recorded. The reverse setting was taken as a 100% prevalence of the left eye. Offsets between 0′ and 2.25′ were transformed linearly to the percent scale. For example, a shift of the upper, posterior triangle by 1.125′ to the left was taken as 50% prevalence of the right eye. A schematic diagram of the procedure is depicted in Fig. 2.

2.2. Haase Stereo-balance Test for ocular prevalence

Two triangles were presented one above and the other below a central object, which consisted of a disc and two measuring scales (Fig. 3). The triangles were shown with a stereo-disparity of 13′ in relation to the central object. We presented the triangles always behind the central object and asked the subject to observe the horizontal position of the upper triangle with respect to the central object for a period of 10 s. After having memorised the position of the upper triangle as it had appeared at the end of the 10 s, the subject was asked to draw the perceived position on a printout of the central object (Fig. 4).

Note: By presenting the triangles always behind the central object, we deliberately simplified Haase's instruction. His suggestion had been to present the triangles alternately in front or behind the central object (Guidelines for the Correction of Associated Phoria, www.ivbv.org/English.htm), intending to compare crossed and uncrossed disparities. However, as fixation is not controlled during the test, the observer is free to look at the anterior or posterior object, so that crossed and uncrossed disparities alternate spontaneously. This argument applies to both the upper and lower triangle.

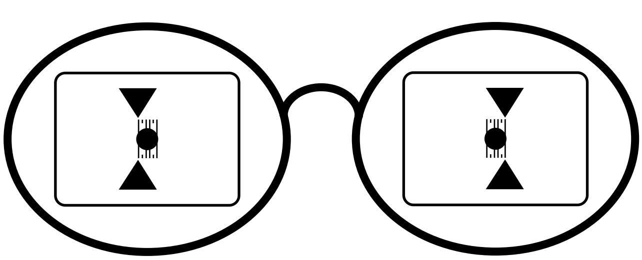

Fig. 3. Haase Stereo-balance Test (Haase, 1995). The triangles are presented behind the central object.

2.3. Parson's Monoptoscope Test for ocular dominance

According to the principle of Parson's Monoptoscope (Duke-Elder, 1968; Miles, 1930), we instructed the subjects to hold a cone-shaped funnel of 20 cm height with both hands in their lap, while looking with both eyes at a small light bulb at a distance of 5 m. Then, the subjects were asked to bring the wide opening of the funnel (diameter 18 cm) with a fast, smooth movement close to their eyes, and to orientate the narrow opening of the funnel (diameter 1 cm) in a direction that made the light bulb visible. After a short interval, the experimenter identified the sighting eye by alternating a cover between the eyes near the wide opening of the funnel, asking the subjects to indicate the disappearance of the light bulb. This procedure was repeated 10 times.

2.4. Subjects

Subjects (employees of our department or students of medicine, aged between 19 and 33 years, median 24 years) were selected according to the following 4 criteria: (1) visual acuity with spherical and cylindrical spectacle correction at least 1.0 in each eye, (2) difference between visual acuity of both eyes not more than by a factor of 1.26, (3) anisometropia in spherical and cylindrical corrections 0.5 D or less, and (4) absence of strabismus, ascertained with the unilateral cover-test. The subjects wore their spherical and cylindrical corrections and

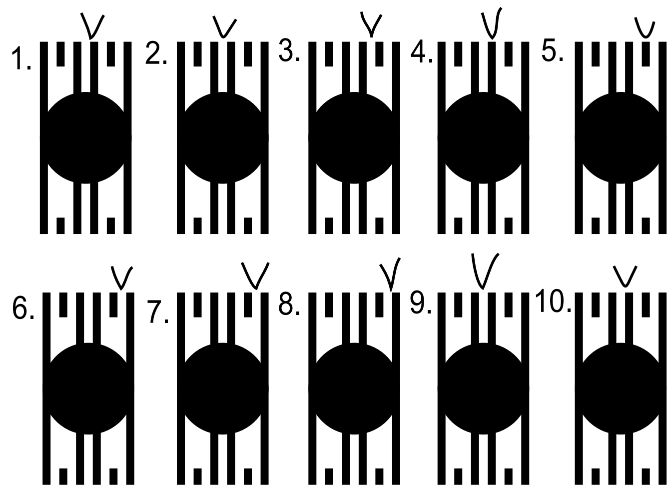

Fig. 4. Template with 10 markings drawn in by subject #9 according to his percept while looking at the Haase Stereo-balance Test.

looked at the tests with their trunk and head directed straight ahead. They were not instructed to fixate either the posterior or the anterior target. We explained to the subjects that the study was designed to compare methods for measuring the contribution of each eye to binocular vision. Each subject gave written consent to participate in the experiments.

2.5. First experiment: influence of a neutral-grey filter and of full occlusion

Six subjects performed the Freiburg Test and the Haase Test under three different conditions: (1) without a filter, (2) with a neutral-grey filter of 3% transmission placed before one eye, and (3) with full occlusion of one eye. Each of the 3 conditions was tested twice in an interleaved block design (1, 2, 3, 3, 2, 1). One block consisted of 10 stimulus presentations. Three of the subjects started with the Freiburg and the three others with the Haase Test. The neutral-grey filter and the full occlusion were placed before the eye that had been prevalent in the no-filter condition of the primarily performed test. In the filter condition, each trial was followed by a break of 10 s, in which subjects took down the filter. The purpose of this step was to limit dark adaptation of the eye under filter.

2.6. Second experiment: distribution of ocular prevalence and dominance

Twenty-three subjects performed the Freiburg and the Haase Tests twice in an interleaved block design, starting in alternate succession either with the Freiburg (F) or the Haase Test (H): 1st subject FHHF, 2nd subject HFFH, 3rd subject FHHF and so forth. Each block consisted of 10 stimulus presentations. Three of the 23 subjects were excluded from the evaluation because they experienced double vision when looking at the Haase Test. None of the subjects saw double with the Freiburg Test. The remaining 20 subjects also performed Parson's Monoptoscope Test for ocular dominance.

3. Results

3.1. First experiment: influence of the neutral-grey filter and of full occlusion

The neutral-grey filter in front of one eye shifted the ocular prevalence in all 6 subjects (Fig. 5). The average and standard deviation was $43 \pm 12\%$ in the Freiburg and $73 \pm 16\%$ in the Haase Test. Full occlusion of one eye resulted in a prevalence of the other eye of $96.4 \pm 7.5\%$ in the Freiburg and of $100 \pm 0\%$ in the Haase Test.

3.2. Second experiment: distribution of ocular prevalence

In the 20 subjects, a prevalence of the right and the left eye occurred with similar frequency (Fig. 6). Lumping the prevalence of the right and the left eye together and dividing the magnitude into 6 classes, the following results were obtained:

	Magnitude of ocular prevalence					
	0–10%	10– 20%	20–40%	40–60%	60–80%	80–100%
Freiburg Test (number of subjects)	7	2	5	6	0	0
Haase Test (number of subjects)	6	4	2	5	2	1

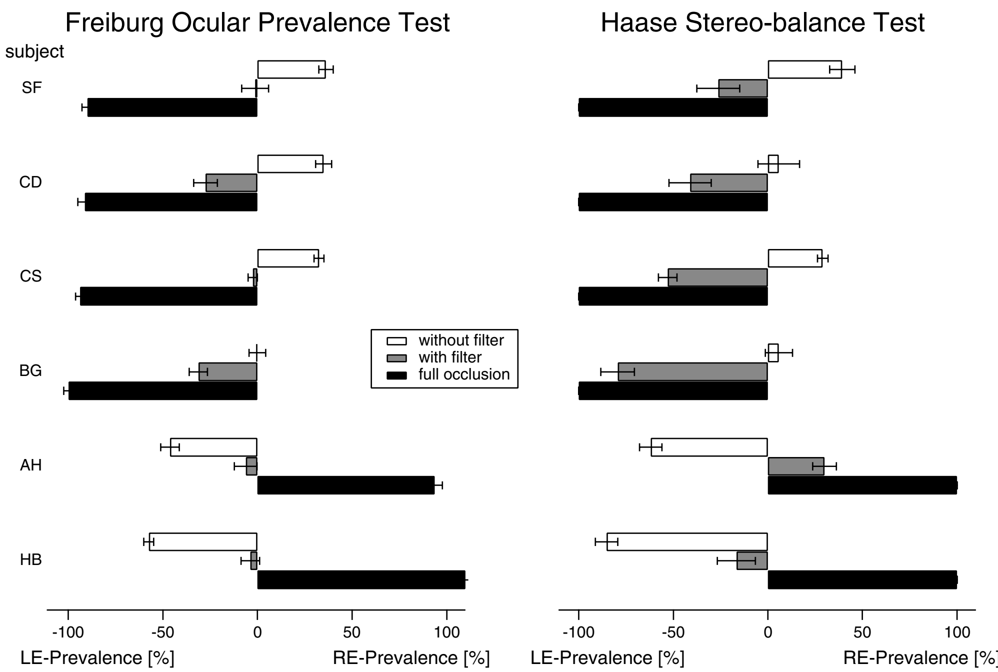

Fig. 5. Ocular prevalence without a filter, with a neutral-grey filter of 3% transmission and with full occlusion in front of one eye. The results obtained in 6 subjects with the Freiburg Test (left) and the Haase Test (right) are arranged for each subject in the same line. Average of 20 stimulus presentations ±SEM (standard error of the mean).

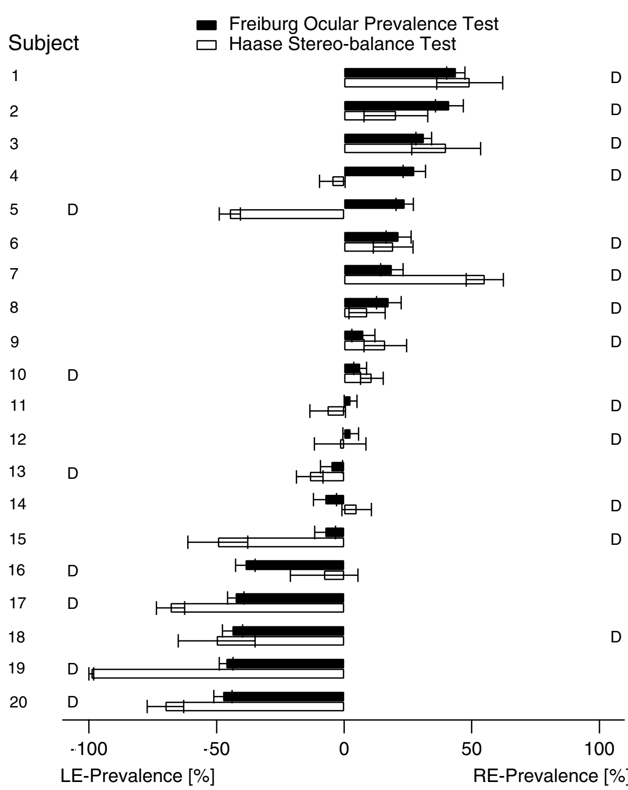

Fig. 6. Ocular prevalence (average of 20 stimulus presentations ±SEM) in 20 subjects, arranged according to the amount of right eye prevalence in the Freiburg Test (black bars). The results obtained with the Haase Test are depicted in white. The ocular dominance determined with Parson's Monoptoscope Test is indicated with right or left position of the letter "D".

An ocular prevalence of more than 10% occurred in 13 of the 20 subjects at the Freiburg Test and in 14 of the 20 subjects at the Haase Test. Averaging the results of all 20 subjects, the ocular prevalence at the Freiburg Test was 24.1% and at the Haase Test 32.0% ($p = 0.08$, Wilcoxon-Test). The mean standard error at the Freiburg Test was ±3.8% and at the Haase Test ±8.2% ($p < 0.001$, Wilcoxon-Test).

In most subjects, the Freiburg Test and the Haase Test revealed the same eye as being prevalent. A marked discrepancy occurred only in subject #5 with a 24% prevalence of the right eye in the Freiburg and a 45% prevalence of the left eye in the Haase Test. This discrepancy was confirmed in a repetition of both tests, although the amounts of prevalence were less.

3.3. Second experiment: distribution of ocular dominance

Within the 10 trials, the result of Parson's Monoptoscope Test was concordant in favour of one eye in each of the 20 subjects. Thirteen subjects indicated a dominance of their right, 7 of their left eye (Fig. 6). In 15 of the 20 subjects, the dominant coincided with the prevalent eye.

4. Discussion

Parson's Monoptoscope Test, which forces subjects to choose between their right and left eyes, revealed a dominance of the right eye in 13 and a dominance of the left eye in 7 of our 20 subjects. These numbers are consistent with those of Miles (1930) who, using a similar instrument, found right-eyedness in 64% and left-eyedness in 34% of his 600 subjects. Only 2% did not show a marked dominance on repeated testing.

For a graded quantification of the balance between the two eyes, we measured ocular prevalence using two strategies: alignment of adjustable stereo-targets (Freiburg Ocular Prevalence Test) and estimation of horizontal distance between stationary stereo-targets (Haase Stereo-balance Test). In our first experiment, both strategies proved to be suitable to measure certain fractions of ocular prevalence: a neutral-grey filter in front of one eye shifted the prevalence by about 50%. This finding is consistent with that of Mansfield and Legge (1996) who demonstrated that the subjective alignment of depth features can be shifted by reducing the contrast for one eye.

The main result of the present study is revealed in the second experiment. We found that *spontaneous* prevalence of one eye is quite common in subjects with equal monocular vision. A prevalence of more than 10% appeared in 13 of our 20 subjects when we applied the Freiburg Test, and in 14 of our 20 subjects when we applied the Haase Test. Averaging the results of all 20 subjects, the ocular prevalence was 24.1% in the Freiburg and 32.0% in the Haase Test. These data are compatible with those of Sachsenweger (1958) who found ocular prevalence in 66 of 106 subjects, and with those of Erkelens, Muijs, and van Ee (1996) who found ocular prevalence in 3 of 4 subjects.

The reproducibility was better in the Freiburg than in the Haase Test, as indicated by a smaller standard deviation: ±3.8% versus ±8.2%, $p < 0.001$. This advantage appears even more impressive if one takes into account that the Freiburg Test uses a smaller stereo-disparity than the Haase Test (4.5 versus 13′). Hence, the angle of the standard deviation amounted to only $(4.5 \times 0.5 \times 3.8 =) \pm 8.6'$ in the Freiburg Test versus $(13 \times 0.5 \times 8.2 =) \pm 53.3'$ in the Haase Test. The better reproducibility of the Freiburg Test is consistent with the general psychophysical experience that nulling a difference reveals more accurate results than estimating a difference (Ehrenstein & Ehrenstein, 1999).

To avoid any misunderstandings, we would like to emphasise that both the Freiburg and the Haase Tests concern the *relative* visual directions between stereo-disparate objects. They do not bear on the *egocentric* directions in which objects are seen (Howard & Templeton, 1966). Accordingly, the crossing point between the line that connects the far and the near targets when they appear aligned, and the interocular line (Fig. 2), is merely an auxiliary geometrical construction. It allows to define the relative contribution of the two eyes for the directions in which the targets are seen with respect to each other. The crossing point does not define the 'cyclopean eye' (von Helmholtz, 1867, p. 611), which is thought by some as a "logical and a functional necessity" for judging headcentric visual directions (Mapp & Ono, 1999, and Ono, Mapp, & Howard, 2002), whereas others argue that the concept and particularly a certain location of the cyclopean eye is "sometimes inappropriate and always irrelevant" for vision (Erkelens & van Ee, 2002).

4.1. Does ocular prevalence bear any clinical relevance?

Haase (1995) proposed that ocular prevalence indicates fixation disparity. This hypothesis was refuted by search-coil recordings of the eye position: Using the principle of the unilateral covertest, Gerling, de Paz, Schroth, Bach, and Kommerell (2000) switched off the fixation target for the prevalent eye and did not find a refixation movement of the other eye, which should have occurred in the case of a vergence error. Further, Haase's assertion that ocular prevalence can be, and should be eliminated by phoria-correcting prisms in patients who suffer from eye strain, is questionable since Kromeier, Schmitt, Bach, and Kommerell (2002b) demonstrated that ocular prevalence persists under phoria-correcting and vergence-stressing prisms.

Consenting with Lang (1994), we suggest that ocular prevalence may be due to a partial suppression of one eye that helps to disregard double images at stereo-disparities close to the limits of Panum's area. This idea is consistent with the frequent occurrence of ocular prevalence, and fits with a trend found in our study: Ocular prevalence was greater in the Haase Test, which contains a larger stereo-disparity than the Freiburg Test (prevalence 32.0% versus 24.1%, $p = 0.08$).

Our notion that ocular prevalence does not indicate a clinical problem is supported by the observation of Kromeier, Schmitt, Bach, and Kommerell (2002a) that persons with ocular prevalence can have a very high stereo-acuity at their disposal: Using a forced-choice technique in 10 subjects with ocular prevalence, they found stereoscopic thresholds between 1.5″ and 14.5″. Our interpretation of this finding is that partial suppression of one eye, apparent as ocular prevalence and serving a purpose at large stereo-disparities, can be switched off as soon as fine depth discrimination is demanded.

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